

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefit under 35 U.S.C. §119(e) of provisional patent application S.N. 60/221,511, filed July 28, 2000, the contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0002] In one of its aspects, the present invention relates to a foamed isocyanate-based polymer having improved hardness properties. In another of its aspects, the present invention relates to a process for the production of such a foamed isocyanate-based polymer. In yet another of its aspects, the present invention relates to a method for improving the hardness characteristics of an isocyanate-based foam. In yet another of its aspects, the present invention relates to a dispersion of a dendritic macromolecule and an active hydrogen-containing compound useful in the production of foamed isocyanate-based polymer.

DESCRIPTION OF THE PRIOR ART

[0003] Isocyanate-based polymers are known in the art. Generally, those of skill in the art understand isocyanate-based polymers to be polyurethanes, polyureas, polyisocyanurates and mixtures thereof.

[0004] It is also known in the art to produce foamed isocyanate-based polymers. Indeed, one of the advantages of isocyanate-based polymers compared to other polymer systems is that polymerization and foaming can occur in situ. This results in the ability to mould the polymer while it is forming and expanding.

[0005] One of the conventional ways to produce a polyurethane foam is known as the "one-shot" technique. In this technique, the isocyanate, a suitable polyol, a catalyst, water (which acts as a reactive "blowing" agent and can optionally be supplemented with one or more physical blowing agents) and other additives are mixed together at once using, for example, impingement mixing (e.g., high pressure). Generally, if one were to produce a polyurea, the polyol would be replaced with a suitable polyamine. A polyisocyanurate may

result from cyclotrimerization of the isocyanate component. Urethane modified polyureas or polyisocyanurates are known in the art. In either scenario, the reactants would be intimately mixed very quickly using a suitable mixing technique.

[0006] Another technique for producing foamed isocyanate-based polymers is known as the "prepolymer" technique. In this technique, a prepolymer is produced by reacting polyol and isocyanate (in the case of a polyurethane) in an inert atmosphere to form a liquid polymer terminated with reactive groups (e.g., isocyanate moieties and active hydrogen moieties). To produce the foamed polymer, the prepolymer is thoroughly mixed with a lower molecular weight polyol (in the case of producing a polyurethane) or a polyamine (in the case of producing a modified polyurea) in the presence of a curing agent and other additives, as needed.

[0007] Regardless of the technique used, it is known in the art to include a filler material in the reaction mixture. Conventionally, filler materials have been introduced into foamed polymers by loading the filler material into one or both of the liquid isocyanate and the liquid active hydrogen-containing compound (i.e., the polyol in the case of polyurethane, the polyamine in the case of polyurea, etc.). Generally, incorporation of the filler material serves the purpose of conferring so-called loaded building properties to the resulting foam product.

[0008] The nature and relative amounts of filler materials used in the reaction mixture can vary, to a certain extent, depending on the desired physical properties of the foamed polymer product, and limitations imposed by mixing techniques, the stability of the system and equipment imposed limitations (e.g., due to the particle size of the filler material being incompatible with narrow passages, orifices and the like of the equipment).

[0009] One known technique of incorporating a solid material in the foam product for the purpose of improving hardness properties involves the use of a polyol-solids dispersion, particularly one in the form of a graft copolymer polyol. As is known in the art, graft copolymer polyols are polyols, preferably polyether polyols, which contain other organic polymers. It is known that such graft copolymer polyols are useful to confer hardness (i.e., load building) to the resultant polyurethane foam compared to the use of polyols which have not been modified by incorporating the organic polymers. Within graft

copolymer polyols, there are two main categories which may be discussed: (i) chain-growth copolymer polyols, and (ii) step-growth copolymer polyols.

[0010] Chain-growth copolymer polyols generally are prepared by free radical polymerization of monomers in a polyol carrier to produce a free radical polymer dispersed in the polyol carrier. Conventionally, the free radical polymer can be based on acrylonitrile or styrene-acrylonitrile (SAN). The solids content of the polyol is typically up to about 60%, usually in the range of from about 15% to about 40%, by weight of the total weight of the composition (i.e., free radical polymer and polyol carrier). Generally, these chain-growth copolymer polyols have a viscosity in the range of from about 2,000 to about 8,000 centipoise. When producing such chain-growth copolymer polyols, it is known to induce grafting of the polyol chains to the free-radical polymer.

[0011] Step-growth copolymer polyols generally are characterized as follows: (i) PHD (Polyharnstoff Disperion) polyols, (ii) PIPA (Poly Isocyanate Poly Addition) polyols, and (iii) epoxy dispersion polyols. PHD polyols are dispersions of polyurea particles in conventional polyols and generally are formed by the reaction of a diamine (e.g., hydrazine) with a diisocyanate (e.g., toluene diisocyanate) in the presence of a polyether polyol. The solids content of the PHD polyols is typically up to about 50%, usually in the range of from about 15% to about 40%, by weight of the total weight of the composition (i.e., polyurea particles and polyol carrier). Generally, PHD polyols have a viscosity in the range of from about 2,000 to about 6,000 centipoise. PIPA polyols are similar to PHD polyols but contain polyurethane particles instead of polyurea particles. The polyurethane particles in PIPA polyols are formed in situ by reaction of an isocyanate and alkanolamine (e.g., triethanolamine). The solids content of the PIPA polyols is typically up to about 80%, usually in the range of from about 15% to about 70%, by weight of the total weight of the composition (i.e., polyurethane particles and polyol carrier). Generally, PIPA polyols have a viscosity in the range of from about 4,000 to about 50,000 centipoise. See, for example, United States patents 4,374,209 and 5,292,778. Epoxy dispersion polyols are based on dispersions of cured epoxy resins in conventional based polyols. The epoxy particles are purportedly high modulus solids with improved hydrogen bonding characteristics.

[0012] Further information regarding useful graft copolymer polyols may be found, for example, in Chapter 2 of "Flexible Polyurethane Foams" by Herrington and Hock (1997) and the references cited therein.

[0013] Despite the advances made in the art, there exists a continued need for the development of novel load building techniques. Specifically, many of the prior art approaches discussed hereinabove involve the use of relatively expensive materials (e.g., the graft copolymer polyols described above) which can be complicated to utilize in a commercial size facility. Thus, it would be desirable to have a load building technique which could be conveniently applied to polyurethane foam as an alternative to conventional load building techniques. It would be further desirable if the load building technique: was relatively inexpensive and/or improved other properties of the polyurethane foam and/or could be incorporated into an existing production scheme without great difficulty.

SUMMARY OF THE INVENTION

[0014] It is an object of the present invention to provide a novel isocyanate-based polymer foam which obviates or mitigates at least one of the above-mentioned disadvantages of the prior art.

[0015] It is another object of the present invention to provide a novel approach to conferring load building properties to an isocyanate-based polymer foam.

[0016] It is yet another object of the present invention to provide a novel process for production of an isocyanate-based polymer foam.

[0017] Accordingly, in one of its objects, the present invention provides a foamed isocyanate-based polymer derived from a reaction mixture comprising an isocyanate, an active hydrogen-containing compound, a dendritic macromolecule and a blowing agent; wherein at least a 15% by weight of the dendritic macromolecule may be mixed with a polyether polyol having an OH number less than about 40 mg KOH/g to form a stable liquid at 23°C.

[0018] In another of its aspects, the present invention provides a foamed isocyanate-based polymer derived from an isocyanate and an active hydrogen-containing compound, the polymer having a cellular matrix comprising a plurality of interconnected struts, the active

hydrogen-containing compound conferring to the cellular matrix a load efficiency of at least about 15 Newtons (preferably from about 15 to about 50 Newtons, more preferably from about 20 to about 45 Newtons, most preferably from about 25 to about 35 Newtons).

[0019] In yet another of its aspects, the present invention provides a foamed isocyanate-based polymer having a cellular matrix comprising a plurality of interconnected struts, the cellular matrix: (i) having a load efficiency of at least about 15 Newtons, and (ii) being substantially free of particulate material.

[0020] In yet another of its aspects, the present invention provides a process for producing a foamed isocyanate-based polymer comprising the steps of:

contacting an isocyanate, an active hydrogen-containing compound, a dendritic macromolecule and a blowing agent to form a reaction mixture; and

expanding the reaction mixture to produce the foamed isocyanate-based polymer;

wherein at least a 15% by weight of the dendritic macromolecule may be mixed with a polyether polyol having an OH number less than about 40 mg KOH/g to form a stable liquid at 23°C.

[0021] In yet another of its aspects, the present invention provides a foamed isocyanate-based polymer derived from a reaction mixture comprising an isocyanate, an active hydrogen-containing compound, a dendritic macromolecule and a blowing agent; the foamed isocyanate-based polymer having an Indentation Force Deflection loss when measured pursuant to ASTM D3574 which is less than that of a reference foam produced by substituting a copolymer polyol for the dendritic macromolecule in the reaction mixture, the foamed isocyanate-based polymer and the reference foam having substantially the same density and Indentation Force Deflection when measured pursuant to ASTM D3574 (50 in² indenter; 15" x 15" x 4" sample size; 25°C, 50% relative humidity).

[0022] In yet another of its aspects, the present invention provides a foamed isocyanate-based polymer derived from a reaction mixture comprising an isocyanate, an active hydrogen-containing compound, a dendritic macromolecule and a blowing agent; the foamed isocyanate-based polymer having thickness loss when measured pursuant to ASTM D3574 which is less than that of a reference foam produced by substituting a copolymer

polyol for the dendritic macromolecule in the reaction mixture, the foamed isocyanate-based polymer and the reference foam having substantially the same density and Indentation Force Deflection when measured pursuant to ASTM D3574.

[0023] As used throughout this specification, the term "isocyanate-based polymer" is intended to mean, inter alia, polyurethane, polyurea and polyisocyanurate. Further, the terms "dendritic polymer" and "dendritic macromolecule" are used interchangeably throughout this specification. These materials are generally known in the art. See, for example, any one of:

Tomalia et al in Angew. Chem. Int. Ed. Engl. 29 pages 138-175 (1990);
United States patent 5,418,301 [Hult et al (Hult)]; and
United States patent 5,663,247 [Sörensen et al (Sörensen)].

[0024] The present inventors have surprisingly and unexpectedly discovered that a sub-group of dendritic macromolecules is particularly advantageous to confer load building properties in an isocyanate-based foam. Indeed, as will be developed in the Examples hereinbelow, its possible to utilize the sub-group of dendritic macromolecules to partially or fully displace copolymer polyols conventionally used to confer load building characteristics to isocyanate-based polymer foams. The sub-group of dendritic macromolecules is described in detail in copending United States patent application S.N. 60/221,512, filed on July 28, 2000 in the name of Pettersson et al. and the contents of which are hereby incorporated by reference.

[0025] Preferred aspects of the present invention relate to the ability to mix at least about 15% by weight of the dendritic macromolecule with a polyether polyol having an OH number less than about 40 mg KOH/g to form a stable liquid at 23°C. As used throughout this specification, the term "stable liquid", when used in connection with this solubility parameter of the dendritic macromolecule, is intended to mean that the liquid formed upon mixing the dendritic macromolecule and the polyol has a substantial constant light transmittance (transparent at one extreme and opaque at the other extreme) for at least 2 hours, preferably at least 30 days, more preferably a number of months, after production of

the mixture. Practically, in one embodiment, the stable liquid will be in the form a clear, homogeneous liquid (e.g., a solution) which will remain as such over time. In another embodiment, the stable liquid will be in the form an emulsion of (at least a portion of) the dendritic macromolecule in the polyol which will remain as such over time - i.e., the dendritic macromolecule will not settle out over time.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

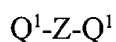
[0026] The present invention is related to foamed isocyanate-based polymer and to a process for production thereof. Preferably, the isocyanate-based polymer is selected from the group comprising polyurethane, polyurea, polyisocyanurate, urea-modified polyurethane, urethane-modified polyurea, urethane-modified polyisocyanurate and urea-modified polyisocyanurate. As is known in the art, the term "modified", when used in conjunction with a polyurethane, polyurea or polyisocyanurate means that up to 50% of the polymer backbone forming linkages have been substituted.

[0027] The present foamed isocyanate-based polymer is produced from a reaction mixture which comprises an isocyanate and an active hydrogen-containing compound.

[0028] The isocyanate suitable for use in the reaction mixture is not particularly restricted and the choice thereof is within the purview of a person skilled in the art. Generally, the isocyanate compound suitable for use may be represented by the general formula:



wherein i is an integer of two or more and Q is an organic radical having the valence of i. Q may be a substituted or unsubstituted hydrocarbon group (e.g., an alkylene or arylene group). Moreover, Q may be represented by the general formula:



wherein Q¹ is an alkylene or arylene group and Z is chosen from the group comprising -O-, -O-Q¹-, -CO-, -S-, -S-Q¹-S- and -SO₂-. Examples of isocyanate compounds which fall within the scope of this definition include hexamethylene diisocyanate, 1,8-diisocyanato-p-methane, xylyl diisocyanate, (OCNCH₂CH₂CH₂OCH₂O)₂, 1-methyl-2,4-diisocyanatocyclohexane, phenylene diisocyanates, tolylene diisocyanates, chlorophenylene diisocyanates, diphenylmethane-4,4'-diisocyanate, naphthalene-1,5-diisocyanate, triphenylmethane-4,4',4''-triisocyanate and isopropylbenzene-alpha-4-diisocyanate.

[0029] In another embodiment, Q may also represent a polyurethane radical having a valence of i. In this case Q(NCO)_i is a compound which is commonly referred to in the art as a prepolymer. Generally, a prepolymer may be prepared by reacting a stoichiometric excess of an isocyanate compound (as defined hereinabove) with an active hydrogen-containing compound (as defined hereinafter), preferably the polyhydroxyl-containing materials or polyols described below. In this embodiment, the polyisocyanate may be, for example, used in proportions of from about 30 percent to about 200 percent stoichiometric excess with respect to the proportion of hydroxyl in the polyol. Since the process of the present invention may relate to the production of polyurea foams, it will be appreciated that in this embodiment, the prepolymer could be used to prepare a polyurethane modified polyurea.

[0030] In another embodiment, the isocyanate compound suitable for use in the process of the present invention may be selected from dimers and trimers of isocyanates and diisocyanates, and from polymeric diisocyanates having the general formula:



wherein both i and j are integers having a value of 2 or more, and Q'' is a polyfunctional organic radical, and/or, as additional components in the reaction mixture, compounds having the general formula:



wherein i is an integer having a value of 1 or more and L is a monofunctional or polyfunctional atom or radical. Examples of isocyanate compounds which fall with the scope of this definition include ethylphosphonic diisocyanate, phenylphosphonic diisocyanate, compounds which contain a =Si-NCO group, isocyanate compounds derived from sulphonamides (QSO₂NCO), cyanic acid and thiocyanic acid.

[0031] See also for example, British patent number 1,453,258, for a discussion of suitable isocyanates.

[0032] Non-limiting examples of suitable isocyanates include: 1,6-hexamethylene diisocyanate, 1,4-butylene diisocyanate, furfurylidene diisocyanate, 2,4-toluene diisocyanate, 2,6-toluene diisocyanate, 2,4'-diphenylmethane diisocyanate, 4,4'-diphenylmethane diisocyanate, 4,4'-diphenylpropane diisocyanate, 4,4'-diphenyl-3,3'-dimethyl methane diisocyanate, 1,5-naphthalene diisocyanate, 1-methyl-2,4-diisocyanate-5-chlorobenzene, 2,4-diisocyanato-s-triazine, 1-methyl-2,4-diisocyanato cyclohexane, p-phenylene diisocyanate, m-phenylene diisocyanate, 1,4-naphthalene diisocyanate, dianisidine diisocyanate, bitolylene diisocyanate, 1,4-xylylene diisocyanate, 1,3-xylylene diisocyanate, bis-(4-isocyanatophenyl)methane, bis-(3-methyl-4-isocyanatophenyl)methane, polymethylene polyphenyl polyisocyanates and mixtures thereof. A more preferred isocyanate is selected from the group comprising 2,4-toluene diisocyanate, 2,6-toluene diisocyanate and mixtures thereof, for example, a mixture comprising from about 75 to about 85 percent by weight 2,4-toluene diisocyanate and from about 15 to about 25 percent by weight 2,6-toluene diisocyanate. Another more preferred isocyanate is selected from the group comprising 2,4'-diphenylmethane diisocyanate, 4,4'-diphenylmethane diisocyanate and mixtures thereof. The most preferred isocyanate is a mixture comprising from about 15 to about 25 percent by weight 2,4'-diphenylmethane diisocyanate and from about 75 to about 85 percent by weight 4,4'-diphenylmethane diisocyanate.

[0033] If the process is utilized to produce a polyurethane foam, the active hydrogen-containing compound is typically a polyol. The choice of polyol is not particularly restricted and is within the purview of a person skilled in the art. For example, the polyol may be a hydroxyl-terminated backbone of a member selected from the group comprising polyether, polyester, polycarbonate, polydiene and polycaprolactone. Preferably, the polyol is selected

from the group comprising hydroxyl-terminated polyhydrocarbons, hydroxyl-terminated polyformals, fatty acid triglycerides, hydroxyl-terminated polyesters, hydroxymethyl-terminated polyesters, hydroxymethyl-terminated perfluoromethylenes, polyalkyleneether glycols, polyalkylenearyleneether glycols and polyalkyleneether triols. More preferred polyols are selected from the group comprising adipic acid-ethylene glycol polyester, poly(butylene glycol), poly(propylene glycol) and hydroxyl-terminated polybutadiene - see, for example, British patent number 1,482,213, for a discussion of suitable polyols. Preferably, such a polyether polyol has a molecular weight in the range of from about 200 to about 10,000, more preferably from about 2,000 to about 7,000, most preferably from about 2,000 to about 6,000.

[0034] If the process is utilized to produce a polyurea foam, the active hydrogen-containing compound comprises compounds wherein hydrogen is bonded to nitrogen. Preferably such compounds are selected from the group comprising polyamines, polyamides, polyimines and polyolamines, more preferably polyamines. Non-limiting examples of such compounds include primary and secondary amine terminated polyethers. Preferably such polyethers have a molecular weight of greater than about 230 and a functionality of from 2 to 6. Such amine terminated polyethers are typically made from an appropriate initiator to which a lower alkylene oxide is added with the resulting hydroxyl terminated polyol being subsequently aminated. If two or more alkylene oxides are used, they may be present either as random mixtures or as blocks of one or the other polyether. For ease of amination, it is especially preferred that the hydroxyl groups of the polyol be essentially all secondary hydroxyl groups. Typically, the amination step replaces the majority but not all of the hydroxyl groups of the polyol.

[0035] The reaction mixture used to produce the present foamed isocyanate-based polymer typically will further comprise a blowing agent. As is known in the art water can be used as an indirect or reactive blowing agent in the production of foamed isocyanate-based polymers. Specifically, water reacts with the isocyanate forming carbon dioxide which acts as the effective blowing agent in the final foamed polymer product. Alternatively, the carbon dioxide may be produced by other means such as unstable compounds which yield carbon dioxide (e.g., carbamates and the like). Optionally, direct organic blowing agents

may be used in conjunction with water although the use of such blowing agents is generally being curtailed for environmental considerations. The preferred blowing agent for use in the production of the present foamed isocyanate-based polymer comprises water.

[0036] It is known in the art that the amount of water used as an indirect blowing agent in the preparation of a foamed isocyanate-based polymer is conventionally in the range of from about 0.5 to as high as about 40 or more parts by weight, preferably from about 1.0 to about 10 parts by weight, based on 100 parts by weight of the total active hydrogen-containing compound content in the reaction mixture. As is known in the art, the amount of water used in the production of a foamed isocyanate-based polymer typically is limited by the fixed properties expected in the foamed polymer and by the tolerance of the expanding foam towards self structure formation.

[0037] The reaction mixture used to produce the present foamed isocyanate-based polymer typically will further comprise a catalyst. The catalyst used in the reaction mixture is a compound capable of catalyzing the polymerization reaction. Such catalysts are known, and the choice and concentration thereof in the reaction mixture is within the purview of a person skilled in the art. See, for example, United States patents 4,296,213 and 4,518,778 for a discussion of suitable catalyst compounds. Non-limiting examples of suitable catalysts include tertiary amines and/or organometallic compounds. Additionally, as is known in the art, when the objective is to produce an isocyanurate, a Lewis acid must be used as the catalyst, either alone or in conjunction with other catalysts. Of course it will be understood by those skilled in the art that a combination of two or more catalysts may be suitably used.

[0038] In a preferred aspect of the present invention a dendritic macromolecule is incorporated in the present foamed isocyanate-based polymer. Preferably, the dendritic macromolecule has the following characteristics:

- (i) an active hydrogen content of greater than about 3.8 mmol/g, more preferably greater than about 4.0 mmol/g, even more preferably in the range of from about 3.8 to about 10 mmol/g; even more preferably in the range of from about 3.8 to about 7.0 mmol/g; even more

preferably in the range of from about 4.0 to about 8.0 mmol/g; most preferably in the range of from about 4.4 to about 5.7 mmol/g;

- (ii) an active hydrogen functionality of at least about 8; more preferably at least about 16; even more preferably in the range of from about 16 to about 70; even more preferably in the range of from about 18 to about 60; even more preferably in the range of from about 17 to about 35; most preferably in the range of from about 20 to about 30;
- (iii) at least about 15%, more preferably from about 15% to about 50%, even more preferably from about 15% to about 40%, even more preferably from about 15% to about 30%, by weight of the dendritic macromolecule may be mixed with a polyether polyol having an OH number less than about 40, more preferably from about 25 to about 35, mg KOH/g to form a stable liquid at 23°C.

Further details on the dendritic macromolecule may be obtained from copending United States patent application S.N. 60/221,512, filed on July 28, 2000 and from International patent application PCT/SE•/• filed on June 29, 2001 (claiming priority from the '512 application), both in naming Pettersson et al.

[0039] As will be clearly understood by those of skill in the art, it is contemplated that conventional additives in the polyurethane foam art can be incorporated in the reaction mixture created during the present process. Non-limiting examples of such additives include: surfactants (e.g., organo-silicone compounds available under the tradename L-540 Union Carbide), cell openers (e.g., silicone oils), extenders (e.g., halogenated paraffins commercially available as Cereclor S45), cross-linkers (e.g., low molecular weight reactive hydrogen-containing compositions), pigments/dyes, flame retardants (e.g., halogenated organo-phosphoric acid compounds), inhibitors (e.g., weak acids), nucleating agents (e.g., diazo compounds), anti-oxidants, and plasticizers/stabilizers (e.g., sulphonated aromatic

compounds). The amounts of these additives conventionally used would be within the purview of a person skilled in the art.

[0040] The following Examples illustrate the use of the dendritic polymer in a typical isocyanate-based high resilience (HR) based foam. In each Example, the isocyanate-based foam was prepared by the pre-blending of all resin ingredients including polyols, copolymer polyols, catalysts, water, and surfactants as well as the dendritic macromolecule of interest. The isocyanate was excluded from this mixture. The resin blend and isocyanate were then mixed at an isocyanate index of 100 using a conventional two-stream mixing technique and dispensed into a preheated mold (65°C) having the dimensions 38.1 cm x 38.1 cm x 10.16 cm. The mold was then closed and the reaction allowed to proceed until the total volume of the mold was filled. After approximately 6 minutes, the isocyanate-based foam was removed and, after proper conditioning, the properties of interest were measured. This methodology will be referred to in the following Examples as the General Procedure.

[0041] In the Examples, the following materials were used:

E837, base polyol, commercially available from Lyondell;

E850, a 43% solids content copolymer (SAN) polyol, commercially available from Lyondell;

HBP, a dendritic macromolecule produced in Example A hereinbelow and discussed in more detail in copending United States patent application S.N. 60/221,512, filed on July 28, 2000 in the name of Pettersson et al.;

DEAO LF, diethanolamine, a cross-linking agent commercially available from Air Products;

Glycerin, a cross-linking agent, commercially available from Van Waters & Rogers;

Water, indirect blowing agent;

Dabco 33LV, a gelation catalyst, commercially available from Air Products;

Niax A-1, a blowing catalyst, commercially available from Witco;

DC 5169, a surfactant, commercially available from Air Products;

Y-10184, a surfactant, commercially available from Witco; and

Lupranate T80, isocyanate (TDI), commercially available from BASF.

Unless otherwise stated, all parts reported in the Examples are parts by weight.

Example A

[0042] 100.0 kg of an alkoxyated pentaerythritol with a hydroxyl value of 630 mg KOH/g, 1055 kg of 2,2-dimethylolpropionic acid (Bis-MPA, Perstorp Specialty Chemicals) and 8.5 kg of paratoluenic sulphonic acid were cold mixed in a reactor equipped with a heating system with accurate temperature control, a mechanical stirrer, a pressure gauge, a vacuum pump, a cooler, nitrogen inlet and a receiver. The mixture was heated carefully during slow stirring to a temperature of 140°C. Slow stirring of the mixture at this temperature was maintained at atmospheric pressure until all 2,2-dimethylolpropionic acid was dissolved and the reaction mixture formed a fully transparent solution. The stirring speed was then significantly increased and vacuum was applied to a pressure of 30 mbar. Reaction water immediately started to form, which was collected in the receiver. The reaction was allowed to continue for a further 7 hours, until a final acid value of 8.9 mg KOH/g was obtained. This corresponded to a chemical conversion of ~98%.

[0043] The obtained dendritic polymer had the following characteristics:

Final acid value:	8.9 mg KOH/g
Final hydroxyl value:	489 mg KOH/g
Peak molecular weight:	3490 g/mole
Mw (SEC):	3520 g/mole
Mn (SEC):	2316 g/mole
PDI (Mw/Mn):	1.52
Average hydroxyl functionality:	30.4 OH-groups/molecule

[0044] The obtained properties were in good agreement with the expected theoretical molecular weight of 3607 g/mole at 100% chemical conversion and a theoretical hydroxyl value of 498 mg KOH/g, which would correspond to a OH-functionality of 32.

[0045] 25.0 kg of the dendritic polymer, 8.4 kg of an aliphatic acid with nine carbons with an acid value of 363 mg KOH/g and 3.3 kg of xylene were charged to a reactor equipped with a heating system with accurate temperature control, a mechanical stirrer, a pressure gauge, a vacuum pump, a dean-stark device for azeotropic removal of water, a cooler, nitrogen inlet and a receiver. The mixture was heated under stirring with a nitrogen flow of 500-600 l/h through the reaction mixture from room temperature up to 170°C. At this temperature all xylene was refluxing and the reaction water which started to form was removed by azeotropic distillation. The reaction was allowed to continue for a further 1.5 hours at 170°C, after which the reaction temperature was increased to 180°C. The reaction mixture was kept at this temperature for a further 2.5 hours until an acid value of 5.7 mg KOH/g was obtained. Full vacuum was then applied to the reactor to remove all xylene from the final product.

[0046] The obtained derivatized dendritic polymer had the following characteristics:

Final acid value:	6.2 mg KOH/g
Final hydroxyl value:	293 mg KOH/g
Peak molecular weight:	4351 g/mole
Mw (SEC):	4347 g/mole
Mn (SEC):	1880 g/mole
PDI (Mw/Mn):	2.31
Average hydroxyl functionality:	22.7 OH-groups/molecule

[0047] The obtained properties were in good agreement with the expected theoretical molecular weight of 4699 g/mole at 100% chemical conversion and a theoretical hydroxyl value of 287 mg KOH/g, which would correspond to a OH-functionality of 24.

Examples 1-4

[0048] In Examples 1-4, isocyanate-based foams based on the formulations shown in Table 1 were produced using the General Procedure referred to above. In these Examples, isocyanate-based foams were prepared having a copolymer polyol concentration of 7% (Examples 1 and 3) and 11% (Examples 2 and 4) by weight of resin and having a % H₂O concentration of 3.80% which results in an approximate foam core density of 31 kg/m³. For each level of copolymer polyol concentration, the dendritic macromolecule concentration was increased from 2% by weight of resin (Examples 1 and 2) to 5% by weight of resin (Examples 3 and 4).

[0049] Also reported in Table 1 for each foam is the density and Indentation Force Deflection (IFD) at 50% deflection, measured pursuant to ASTM D3574. As shown, the introduction of the dendritic macromolecule to the isocyanate-based polymer matrix resulted in a 70 N hardness increase for foam containing 7% copolymer (Examples 1 and 3) and a 100N hardness increase for the foam containing 11% copolymer polyol (Examples 2 and 4).

[0050] By this analysis, a “load efficiency”, having units of Newtons/weight % dendritic macromolecule in the resin blend, for each foam may be reported and represents the ability of the dendritic macromolecule to generate firmness in the isocyanate-based foam matrix. As used throughout this specification in connection with the present invention, the term “load efficiency” is defined as the number of Newtons of foam hardness increase per weight % of the dendritic macromolecule added to a base or control resin blend (i.e., typically comprising all ingredients in the foamable composition except the isocyanate). The term “load efficiency”, as used throughout this specification, is intended to have the meaning set out in this paragraph.

[0051] For Examples 1 and 3, the load efficiency of the dendritic macromolecule was determined to be 23.78 Newtons/weight % dendritic macromolecule in the resin blend while for Examples 2 and 4, the load efficiency was determined to be 33.42 Newtons/weight % dendritic macromolecule in the resin blend.

Examples 5-8

[0052] In Examples 5-8, isocyanate-based foams based on formulations shown in Table 2 were produced using the General Procedure referred to above.

[0053] In these Examples, isocyanate-based foams were prepared having copolymer polyol concentrations as those used in Examples 1-4 with a % H₂O concentration of 3.2% which results in an approximate core foam density of 36kg/m³. For each copolymer polyol level used the dendritic macromolecule concentration was increased from 2% to 5% by weight of resin.

[0054] The results of physical property testing are reported in Table 2. As shown, in these Examples, the introduction of the dendritic macromolecule to the isocyanate-based polymer matrix resulted in a 61 Newtons/weight % dendritic macromolecule in the resin blend hardness increase for the foam containing 7% copolymer polyol and a 72 Newtons/weight % dendritic macromolecule in the resin blend hardness increase for the foam containing 11% copolymer polyol. The resulting load efficiency for Examples 5 and 7 was determined to be 20.4 Newtons/weight % dendritic macromolecule in the resin blend while for Examples 6 and 8 the load efficiency was determined to be 23.9 Newtons/weight % dendritic macromolecule in the resin blend.

Examples 9-11

[0055] In Examples 9-11, isocyanate-based foams based on the formulations shown in Table 3 were produced using the General Procedure referred to above.

[0056] In these Examples, isocyanate based foams were prepared in the absence of any copolymer polyol. The isocyanate-based foams were formulated with a % H₂O concentration of 3.8% resulting in an approximate foam core density of 31 kg/m³. The level of the dendritic macromolecule was varied from 6.68% to 13.35% by weight in the resin.

[0057] The results of physical property testing are reported in Table 3. As shown, the introduction of the dendritic macromolecule resulted in a foam hardness increase of 181 Newtons. The load efficiency was calculated by plotting, for each Example, % HBP in the resin (X-axis) versus 50% IFD (Y-axis) and using Sigma Plot™ to plot the line of best fit. The slope of the resulting curve was obtained and reported as the load efficiency, in this case: 27 Newtons/weight % dendritic macromolecule in the resin blend.

Examples 12-14

[0058] In Examples 12-14, isocyanate based foams based on the formulations shown in Table 4 were produced using the General Procedure referred to above.

[0059] In these Examples, isocyanate based foams were prepared in the absence of any copolymer polyol. The isocyanate-based foams were formulated with a %H₂O concentration of 3.2% resulting in an approximate foam core density of 36 kg/m³. The level of the dendritic macromolecule was varied from 6.72% to 13.43% by weight in the resin.

[0060] The results of physical property testing are reported in Table 4. As shown, the introduction of the dendritic macromolecule resulted in a foam hardness increase of 202.5 Newtons. The load efficiency was obtained in the same manner as described in Examples 9-11 and was found to be 30.18 Newtons/weight % dendritic macromolecule in the resin blend.

Examples 15-16

[0061] In Examples 15 and 16, isocyanate-based foams based on the formulations shown in Table 5 were produced using the General Procedure referred to above.

[0062] In these Examples, isocyanate based foams were prepared in the absence of any dendritic macromolecule and used only copolymer polyol as the method by which foam hardness is increased. Thus, it will be appreciated that Examples 15 and 16 are provided for comparative purposes only and are outside the scope of the present invention. The isocyanate-based foams were formulated with a %H₂O concentration of 3.8% resulting in an approximate foam core density of 31 kg/m³. The level of the copolymer polyol was varied from 26% to 8% by weight in the resin.

[0063] The results of physical property testing are reported in Table 4. As shown, the introduction of the copolymer polyol resulted in a foam hardness increase of 192.1 Newtons. The resulting load efficiency is 10.69 Newtons/weight % dendritic macromolecule in the resin blend. As will be apparent, this is significantly less than the load efficiency achieved in the foams produced in Examples 1-14.

[0064] While this invention has been described with reference to illustrative embodiments and examples, the description is not intended to be construed in a limiting sense. Thus, various modifications of the illustrative embodiments, as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to this description. It is therefore contemplated that the appended claims will cover any such modifications or embodiments.

[0065] All publications, patents and patent applications referred to herein are incorporated by reference in their entirety to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated by reference in its entirety.

Table 1

Ingredient	Example			
	1	2	3	4
E837	80.33	70.32	77.2	67.24
E850	17.52	27.53	17.44	27.4
HBP	2.15	2.15	5.36	5.36
DEOA LF	0.91	0.91	0.91	0.91
Glycerin	0.51	0.51	0.51	0.51
H ₂ O	3.95	3.95	3.95	3.95
Dabco 33LV	0.53	0.53	0.53	0.53
NiAx A-1	0.08	0.08	0.08	0.08
DC5169	0.04	0.04	0.04	0.04
Y10184	1.1	1.1	1.1	1.1
Total resin	107.13	107.13	107.13	107.13
Lupranate T80	48.72	48.72	49.33	49.33
Index	100	100	100	100
% H ₂ O	3.8	3.8	3.8	3.8
% SAN in resin	7	11	7	11
% HBP in resin	2	2	5	5
Total dry weight (g)	504	504	510	514
Density (kg/m ³)	31	31	31	31
50% IFD (N)	289	320	359	420

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Table 2

	Example			
Ingredient	5	6	7	8
E837	80.5	70.58	77.41	67.54
E850	17.37	27.29	17.28	27.16
HBP	2.13	2.13	5.31	5.31
DEOA LF	0.91	0.91	0.91	0.91
Glycerin	0.51	0.51	0.51	0.51
H ₂ O	3.28	3.28	3.28	3.28
Dabco 33LV	0.53	0.53	0.53	0.53
Niax A-1	0.08	0.08	0.08	0.08
DC5169	0.04	0.04	0.04	0.04
Y10184	1.1	1.1	1.1	1.1
Total resin	106.45	106.45	106.45	106.45
Lupranate T80	41.87	42.38	41.87	42.38
Index	100	100	100	100
% H ₂ O	3.2	3.2	3.2	3.2
% SAN in resin	7	11	7	11
% HBP in resin	2	2	5	5
Total dry weight (g)	572	576	578	576
Density (kg/m ³)	36	36	36	36
50% IFD (N)	294	335	355	407

Table 3

Ingredient	Example		
	9	10	11
E837	92.8	89.2	85.6
E850	-	-	-
HBP	7.2	10.8	14.4
DEOA LF	1.1	1.1	1.1
Glycerin	0.6	0.6	0.6
H ₂ O	3.93	3.93	3.93
Dabco 33LV	0.411	0.452	0.492
Niax A-1	0.08	0.08	0.08
DC5169	-	-	-
Y10184	1	1	1
Total resin	107.12	107.16	107.2
Lupranate T80	51.737	53.197	54.658
Index	100	100	100
% H ₂ O	3.8	3.8	3.8
% SAN in resin	0	0	0
% HBP in resin	6.68	10.01	13.35
Total dry weight (g)	476	471	473
Density (kg/m ³)	31	31	31
50% IFD (N)	301.6	399.9	482.6
% Hysteresis	34.9	39.3	42.6
Load Efficiency	27.13		

Table 4

Ingredient	Example		
	12	13	14
E837	92.8	89.2	85.6
E850	-	-	-
HBP	7.2	10.8	14.4
DEOA LF	1.1	1.1	1.1
Glycerin	0.6	0.6	0.6
H ₂ O	3.24	3.24	3.24
Dabco 33LV	0.411	0.452	0.492
NiAx A-1	0.08	0.08	0.08
DC5169	-	-	-
Y10184	1	1	1
Total resin	106.43	106.47	106.51
Lupranate T80	45.067	46.527	47.988
Index	100	100	100
% H ₂ O	3.2	3.2	3.2
% SAN in resin	0	0	0
% HBP in resin	6.72	10.08	13.43
Total dry weight (g)	554	554	550
Density (kg/m ³)	36	36	36
50% IFD (N)	307	412.8	509.5
% Hysteresis	28.6	37.3	43.9
Load Efficiency	30.18		

Table 5

Ingredient	Example	
	15	16
E837	34.85	79.95
E850	65.15	20.05
HBP	-	-
DEOA LF	1.1	1.1
Glycerin	0.6	0.6
H ₂ O	3.93	3.93
Dabco 33LV	0.33	0.33
Niax A-1	0.08	0.08
DC5169	-	-
Y10184	1	1
Total resin	107.04	107.04
Lupranate T80	40.817	41.432
Index	100	100
% H ₂ O	3.8	3.8
% SAN in resin	26	8
% HBP in resin	0	0
Total dry weight (g)	550	556
Density (kg/m ³)	31	31
50% IFD (N)	468.4	276.3
% Hysteresis	38.4	29.1
Load Efficiency	10.69	